Testing of Concrete Sleepers and Fastener Systems for the Understanding of Mechanistic Behavior

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Outline

• Background
• UIUC Concrete Sleeper Research Overview
• Objectives of Field Research
• Field Instrumentation Strategy
• Testing at Transportation Technology Center (TTC)
  – Pueblo, CO, USA
• Experimental Results
• Findings
• Future Work
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Fastening System Components

- Rail
- Insulator
- Rail Pad Assembly
- Concrete Crosstie
- Shoulder
- Clip
### 2012 International Survey Results

**Criticality of Problems – North American Responses**

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Average Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deterioration of concrete material beneath the rail</td>
<td>6.43</td>
</tr>
<tr>
<td>Shoulder/fastening system wear or fatigue</td>
<td>6.38</td>
</tr>
<tr>
<td>Cracking from dynamic loads</td>
<td>4.83</td>
</tr>
<tr>
<td>Derailment damage</td>
<td>4.57</td>
</tr>
<tr>
<td>Cracking from center binding</td>
<td>4.50</td>
</tr>
<tr>
<td>Tamping damage</td>
<td>4.14</td>
</tr>
<tr>
<td>Other (e.g. manufactured defect)</td>
<td>3.57</td>
</tr>
<tr>
<td>Cracking from environmental/chemical degradation</td>
<td>3.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Research Topic</th>
<th>Average Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevention or repair of rail seat deterioration</td>
<td>3.60</td>
</tr>
<tr>
<td>Fastening system design</td>
<td>3.60</td>
</tr>
<tr>
<td>Materials design</td>
<td>3.00</td>
</tr>
<tr>
<td>Optimize crosstie design</td>
<td>2.80</td>
</tr>
<tr>
<td>Track system design</td>
<td>2.00</td>
</tr>
</tbody>
</table>
Research Levels (and Examples)

Materials
- Concrete Mix Design
- Rail Seat Surface Treatments
- Pad / Insulator Materials

Components
- Fastener Yield Stress
- Insulator Post Compression
- Concrete Prestress Design

System
- Finite Element Modeling
- Full-Scale Laboratory Experimentation
- Field Experimentation
Research Sponsors and Projects

- CN Fellowship in Rail Engineering (RSD)
- Association of American Railroads (AAR) Technology Scanning Program (RSD and Fastening System Wear and Fatigue)
- Amsted RPS / Amsted Rail, Inc. (Fastening System Wear and Fatigue)
- NEXTRANS Region 5 Transportation Center (RSD)
- Federal Railroad Administration (FRA) (Fastening System Wear and Fatigue, Cracking, Environmental, etc.)
- National University Rail (NURail) (Fastening System Wear and Fatigue)
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FRA Tie and Fastener Project Structure

**Inputs**
- Comprehensive Literature Review
- International Tie and Fastening System Survey
- Loading Regime (Input) Study
- Rail Seat Load Calculation Methodologies
- Involvement of Industry Experts

**Modeling**

**Laboratory Study**

**Field Study**

**Outputs/Deliverables**
- Data Collection
- Document Depository
- Groundwork for Mechanistic Design
- International Survey Report
- Load Path Map
- Parametric Analysis
- State of Practice Report
- Validated Tie and Fastening System Model
- Improved Recommended Practices
Goals of Field Instrumentation

- Lay groundwork for mechanistic design of concrete sleepers and elastic fasteners
- Quantify the demands placed on each component within the system
- Develop an understanding into field loading conditions
- Provide insight for future field testing
- Collect data to validate the UIUC concrete sleeper and fastening system FE model
Areas of Investigation

**Rail**
- Stresses at rail seat
- Strains in the web
- Displacements of web/base

**Fasteners/Insulator**
- Strain of fasteners
- Stresses on insulator

**Concrete Sleepers**
- Moments at the rail seat
- Stresses at rail seat
- Vertical displacements of sleepers
2012 Field Instrumentation Map

- **Full Instrumentation**
  - Lateral, vertical, and chevron strain gauges on rail
  - Embedment and external concrete strain gauges on crosstie
  - Matrix based tactile surface sensors at rail seat (at rail seat W)
  - Linear potentiometers on rail and crosstie

- **Partial Instrumentation**
  - Vertical strain gauges on rail
  - Matrix based tactile surface sensors (at rail seats G and Y)
  - Linear potentiometers on crosstie (at rail seats C and G)
Field Instrumentation Locations

- TTC (Pueblo, CO, USA)
- High Tonnage Loop (HTL)
  - Curve (~5°)
  - Safelok I Fasteners
Field Instrumentation Locations

- TTC (Pueblo, CO, USA)
- Railroad Test Track (RTT)
  - Tangent
  - Safelok I Fasteners
Loading Environment

- Track Loading Vehicle (TLV)
  - Static
  - Dynamic

- Freight Consist
  - 6-axle locomotive
    - 30t axles (393 GRL)
  - Instrumented car
  - Nine cars
    - 30, 33, and 36t axles (263, 286, 315 GRL cars)

- Passenger Consist
  - 4-axle locomotive
    - 29t axles (255 GRL)
  - Nine coaches
    - 10t axles (87 GRL cars)
Fully Instrumented Rail Seats

Instrumented Low Rail
Instrumented Low Rail
Field-side Instrumentation

- Vertical Sleeper Displacement
- Clip Strain
- Vertical Web Strain
- Base Displacement
Gauge-side Instrumentation

Lateral Rail Displacement
Data Acquisition System
Lateral Loads Acting on a Tangent Track

Leading axles of a 10-car freight train (30, 33, and 36t axle loads).
Lateral Loads Acting on a Tangent Track

- No correlation between lateral loads and train speed on tangent track.

Leading axles of a 10-car freight train (30, 33, and 36t axle loads).
Lateral Loads Acting on a Curve Track

- Median load is ~5.5 times larger than what was recorded in tangent track.

Leading axles of a 10-car freight train (30, 33, and 36t axle loads).

Lateral Loads

<table>
<thead>
<tr>
<th>Train Speed, km/h (mph)</th>
<th>Lateral Load (kN)</th>
<th>Lateral Load (kips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 (2)</td>
<td>24 (15)</td>
<td>48 (30)</td>
</tr>
<tr>
<td>66 (45)</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

5° curve
Variability in Loading Conditions

- Negligible correlation between lateral and vertical loads on tangent track.
Effect of Train Speed on Sleeper Displacement

Negligible correlation between train speed and sleeper deflection
Effect of Train Speed on Sleeper Deflection (cont.)

Deflections from train passes do not exceed static response: about 60% (passenger) and 75% (freight)
Variability in Support Conditions

- Curve/Static Loads
- Each point = +22kN (+5kips) vertical load
- Low rail: weak support (slack or gap in support system)
  - Low rail seat forces
- High rail: stiff boundary conditions (well-supported)
  - High rail seat forces
With a weak substructure much of the vertical load (over 75%) is transferred to adjacent sleepers and resisted by the bending of the rail.

Nearly 95% of load is transferred to rail seat.
Preliminary Findings with Potential Design Considerations

• The lateral loading demands were 5.5 times higher in the curve than on tangent track
  – Design should consider specialized components in the curve

• The vertical and lateral loading demands on tangent track are not dependent on train speed
  – Design should not weight speed highly on tangent track

• There is negligible correlation between concurrently acting lateral and vertical loads on tangent track

• Dynamic vertical sleeper displacement never exceeded the purely static response

• Rail seat forces are highly dependent on the stiffness of the substructure and support conditions and can range from below 20% to over 90% of the wheel-rail load
  – Design should incorporate probabilistic loading conditions
Future Work

• Continued **data analysis** to understand the governing mechanics of the system by investigating the:
  – elastic fastener (clamp) strain response
  – number of ties effected simultaneously
  – bending modes of the sleepers
  – pressure magnitude and distribution at the rail seat

• Continued **comparison and validation** of the UIUC finite element model (Chen, Shin)

• Preparation for **instrumentation trip** (Summer 2013)
  – Focus on lateral load path by gathering
    • relative lateral sleeper displacements
    • global lateral sleeper displacements
    • load transferred to the clamp, insulator-post, and shoulder

• Small-scale, **evaluative tests** on Class I Railroads
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Questions?

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